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Color production in blue and green feather barbs of the rosy-faced lovebird

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Abstract

We study experimentally and theoretically the coloration mechanisms of blue and green feather barbs in the rosy-faced lovebird (*Agapornis roseicollis*). Structural characterizations reveal that both the blue and green barbs contain a similar rod-connected amorphous diamond-structured photonic crystal (RAD-PC), producing basically a non-iridescent blue structural color. Numerical simulations show that the existence of a photonic pseudogap in the photonic density of states of the RAD-PC is the physical origin of the non-iridescent blue coloration. The green color in the green barbs is a mixed color coming from the blue structural color in the RAD-PC and the yellow color in the cortex layer that contains a yellow pigment. The optical function of the yellow pigment for achieving a saturated green color is discussed. The interesting coloration mechanisms unraveled may help us get in-depth understandings of the ingenious strategies of color production in nature and valuable inspirations as well.

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Keywords: spongy nanostructure, structural color, photonic pseudogap, pigment, color mixing

1. Introduction

Birds are among the most colorful animals in the world. Generally, there are two ways of color production in avian feathers: pigmentary and structural coloration [1–7]. Pigments can selectively absorb certain wavelengths of light and reflect or scatter others, resulting in pigment-based colors which are substantially important for the color production in nature [8]. On the other hand, structural coloration is caused by the interactions of light with photonic structures via optical effects such as interference, diffraction, scattering, or their combination [9].

Structural colors are widespread in avian feathers [2,10,11]. Revealed photonic structures in feather barbules include single thin films [12,13]), multilayered structures [14–16], and even two-dimensional photonic-crystal struc-

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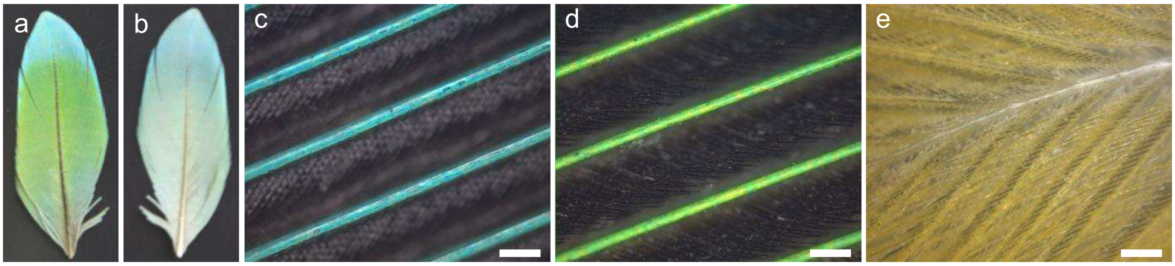

Fig. 1. (a) and (b) Photographs of a rump feather taken on the dorsal and ventral sides, respectively. (c) and (d) Micrographs of the blue and green regions in the rump feather on the dorsal side under 100× magnification, respectively. (e) Micrograph of a yellow feather. Scale bars: (c)–(d) 50 μm.

tures [17,18]. If photonic structures are arranged in an ordered way, iridescent structural coloration is expected. In feather barbs of some birds [19–23], there exist three-dimensional amorphous photonic-crystal structures with only short-range order [24], leading to non-iridescent structural coloration.

In the present work, we study the mechanisms of color production in blue and green feather barbs of a species of parrots, the rosy-faced lovebird (*Agapornis roseicollis*), by structural and spectral characterizations, and numerical simulations. Our aim is to answer how the spongy nanostructures in the blue and green barbs can produce the non-iridescent blue structural coloration and what optical function the yellow pigment in the green barbs plays in the color production.

2. Optical, structural, and spectral characterisations

Feathers of the rosy-faced lovebird under study were obtained from the Shanghai Zoo, Shanghai, China. The rosy-faced lovebird, also known as the peach-faced lovebird, is a small and colorful parrot native to southwestern Africa. Generally, it is mostly green with a peach-colored face and throat, and a blue rump. Fig. 1 shows the optical images of two feathers, one taken from the rump and the other from the breast. Photographs and micrographs were taken by a digital camera (Canon 5D Mark II) and an optical microscope (Leica DM6000 M) connected with a CCD camera, respectively.

On the dorsal side, the rump feather displays a blue color in the top part and a green or greenish yellow color in the middle part (Fig. 1a). On the ventral side, the top part is still blue but the middle part becomes blue or light blue (Fig. 1b). Microscopic observations reveal that the color in the blue region of the rump feather stems completely from the barbs (Fig. 1c) while the barbules are almost transparent and hence do not contribute to the feather coloration. For the breast feather, both barbs and barbules display yellow coloration (Fig. 1e). The yellow color remains unchanged on both the dorsal and ventral sides. As indicated in [25,26], this yellow color is caused by a special class of pigment called psittacofulvins. The barbules attached to the green barbs also contain the yellow pigment. However, its color brightness is much smaller than that of the green barbs, as can be clearly seen from Fig. 1d. As a result, the color in the green region of the rump feather is dominantly from the barbs.

For optical and structural characterizations of microstructures, barbs were embedded in epoxy resin and then cut into 5 μm-thick slices by a slicer (Leica RM2255). Optical transverse cross-sectional images of the sectioned blue and green barbs are shown in Fig. 2. In the blue barb (Fig. 2a), the outer layer is a transparent cortex of keratin. In addition to dark regions, there are regions that display a bright blue color in the central medullary part. In the green barb (Fig. 2b), there exist also bright blue regions in the central medullary part. Note that the blue regions in both the blue and green barbs show similar coloration. This may imply a similar origin of coloration. Different from the blue barb, the cortex of the green barb contains the yellow pigment. To increase the color visibility of the cortex, the green barb was immersed into glycerin. After the glycerin infiltration, the color of the blue regions disappears and becomes transparent, indicating that the blue color is unambiguously a structural color. From Fig. 2c, we can get the distribution of the yellow pigment in the cortex. The perceived color in a green barb depends not only on the color of the blue regions but also on the color of the cortex. Obviously, the distribution of the yellow pigment in the cortex is